7. Optical Properties

7・1 Optical Constants and Light Transmittance

The refractive index of Iupilon / NOVAREX at normal temperature is

$$n_D\ 25°C = 1,585$$

The temperature characteristic is as shown in Fig. 4・1・1−1. The refractive index of other resins was shown in Table 7・1−1.

Table 7・1−1　Refractive index of various plastics

Polymers	n_D 25	Polymers	n_D 25	Polymers	n_D 25
		Polymethyl・methacrylate	1.490−1.500		
Polystyrene	1.590−1.600	(PMMA)	1.570	PETP	1.655
Polymethylstyrene	1.560−1.580	Acrylonitrile・		66 Nylon	1.530
Polyvinyl acetate	1.450−1.470	Styrene（AS		Polyacetal	1.480
		Polytetrafluoroethylene	1.350		
Polyvinyl chloride	1.540	Polutrifluoro ethylene monochloride	1.430	Phenoxy resin	1.598
Polyvinylidene chloride	1.600−1.630	Low density polyethylene	1.510	Polysulphone	1.633
Cellulose acetate	1.490−1.500	High density polyethylene	1.540	SBR	1.520−1.550
Propionic acid	1.460−1.490	Polypropylene	1.490	TPX	1.465
Cellulose Nitrocellulose	1.460−1.510	Polybutyrene	1.500	Epoxy resin	1.550−1.610

The relation between light transmittance and thickness of Iupilon / NOVAREX is shown in Fig. 7・1−1.

The wavelength characteristic is shown in Fig. 7・1−2. The light transmittance wavelength characteristics of polycarbonate and other transparent materials are shown in Fig. 7・1−3.
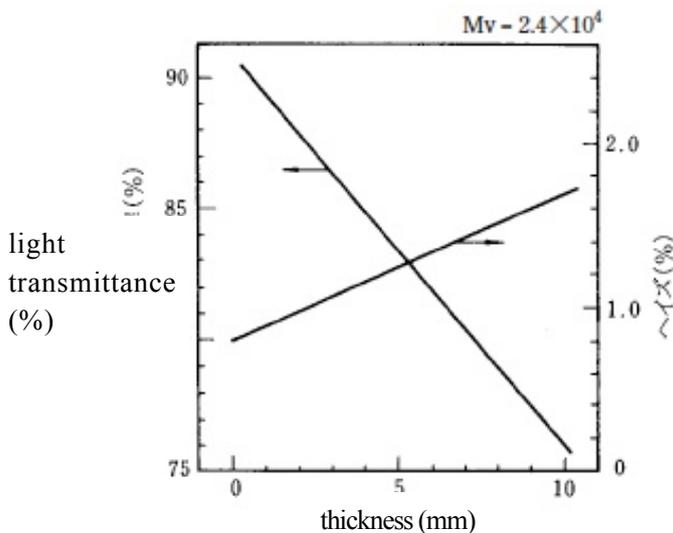

Fig. 7・1−1　Relation between light transmittancee and thickness of Iupilon /
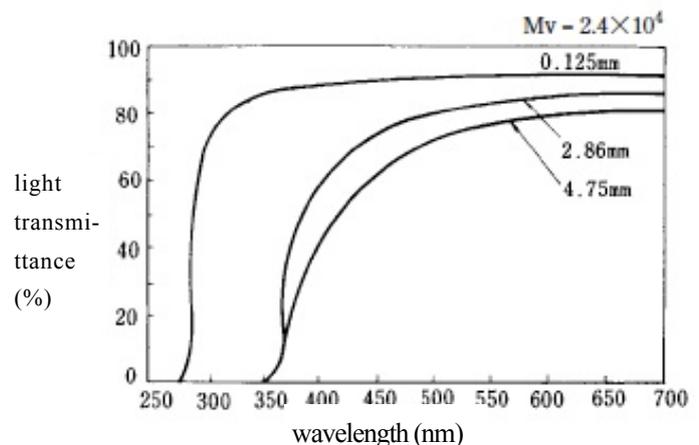
Fig. 7・1−2 Light transmittance of Iupilon / NOVAREX
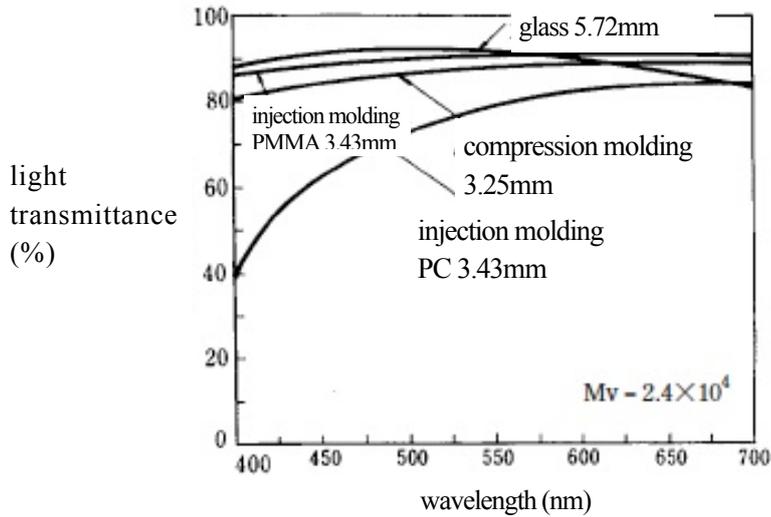
Fig. 7・1－3　Comparison of light transmittance

The change in light transmittance and haze in case of adding filling agent or pigment to Iupilon / NOVAREX is shown in Fig. 7・1－4. The appearance of the change in these characters depends on the characteristics of the additives.
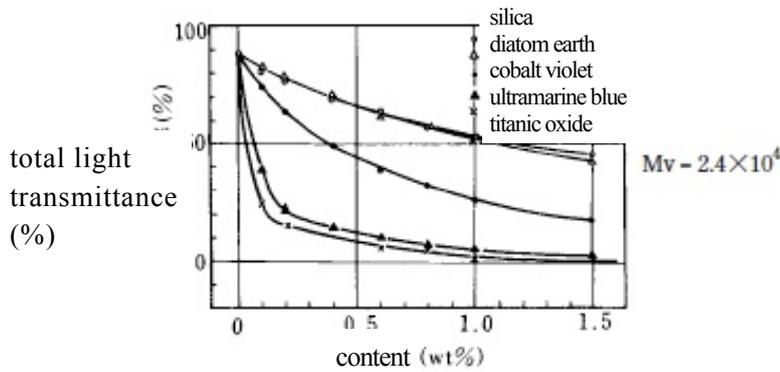

Fig. 7・1－4　Content of filling agent and light transmittance (sample thickness 3mm)

Also, the ultraviolet absorption spectrum and infrared absorption spectrum of Iupilon / NOVAREX are shown in Fig. 7・1－5, 7・1－6 and 7・1－7.
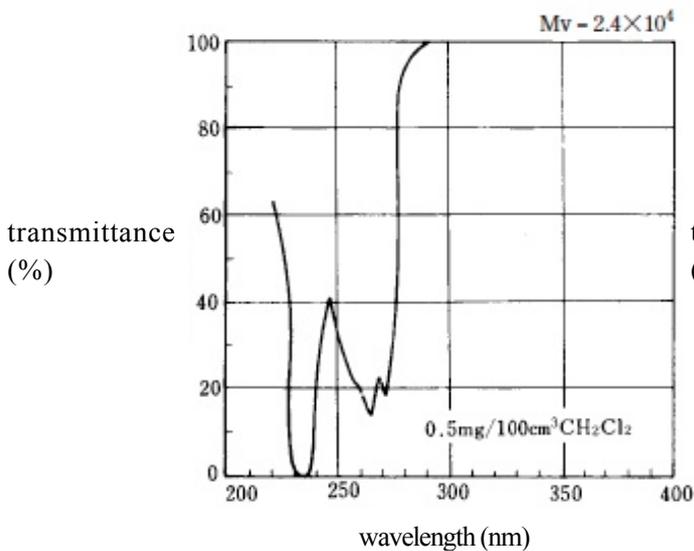

Fig. 7・1－5 Ultraviolet absorption spectrum of Iupilon / NOVAREX
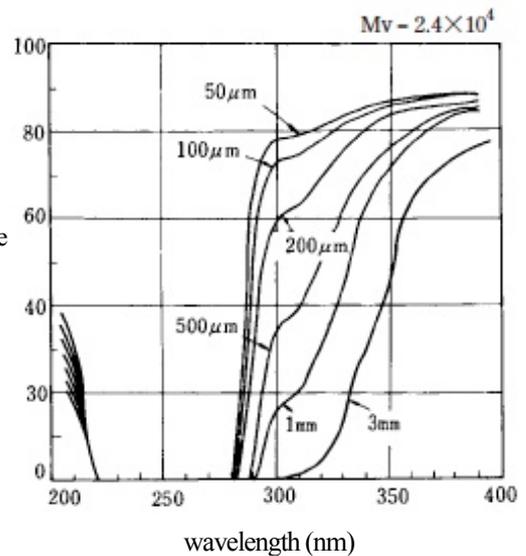
Fig. 7・1－6 Ultraviolet transmittance and thickness of Iupilon / NOVAREX

(Determination method: ASTM D1003)

Sample: S-2000 or 7025A

light transmittance (%)

Thickness 2mm

Thickness 100μ

wavelength (nm)
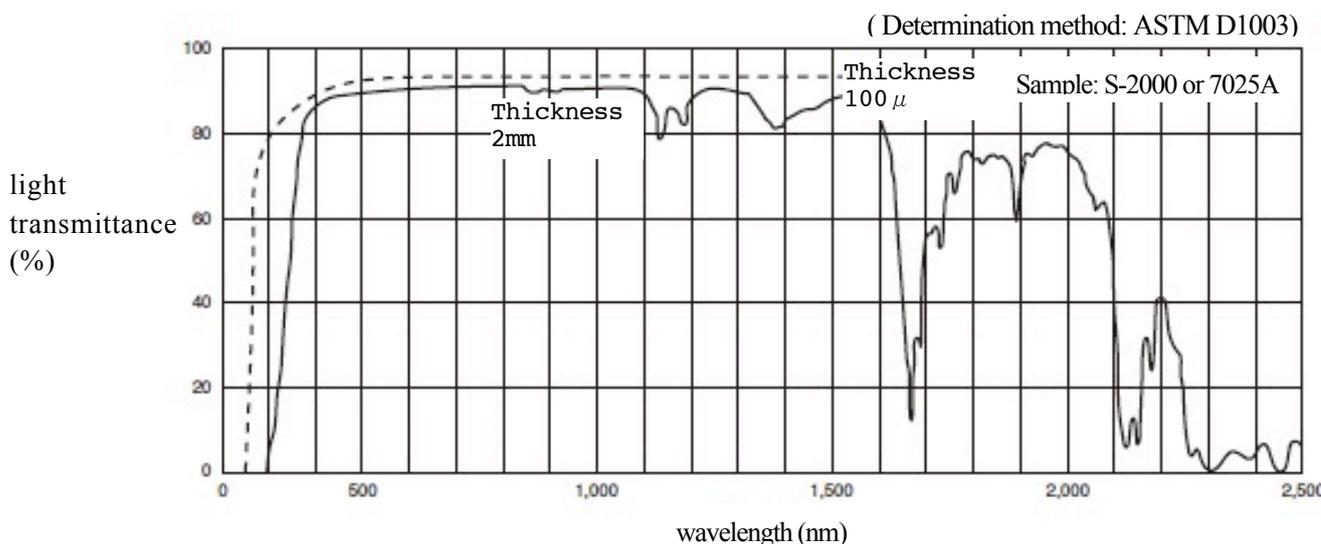
Fig. 7・1－7   Ultraviolet, visible and near-infrared absorption spectrum of Iupilon / NOVAREX


$Mv - 2.4 \times 10^4$

transmittance (%)

wave number (cm^{-1})
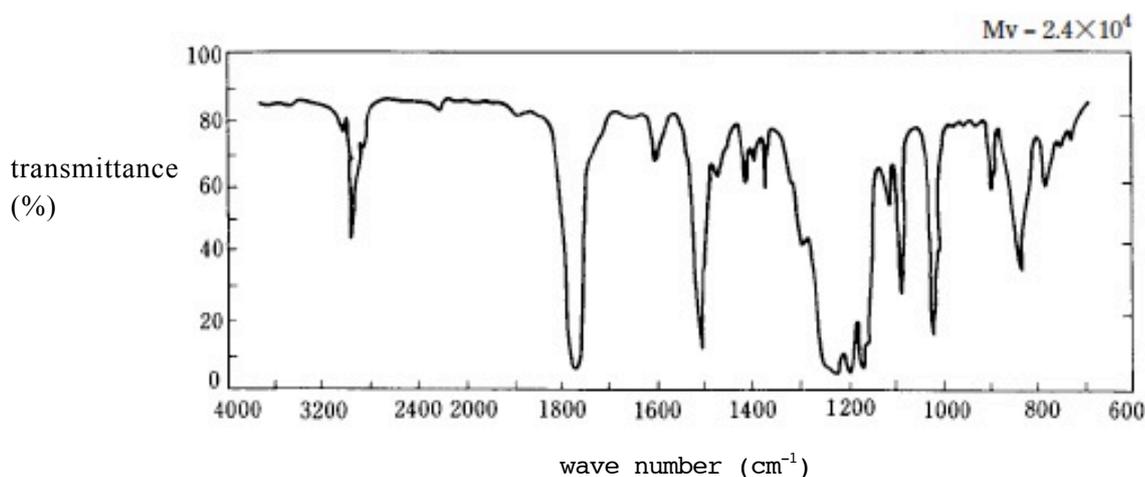
Fig. 7・1－8   Infrared absorption spectrum of Iupilon / NOVAREX

7・2   Weathering (Light) Resistance

As shown in Fig. 7・1－5, Iupilon / NOVAREX has excellent ultraviolet absorption capacity for the short wavelength ultraviolet and excellent durability to sun light and ultraviolet ray by protecting activity as ultraviolet absorber of polymer itself. However, when exposed to strong ultraviolet ray for a long time, degradation of Iupilon / NOVAREX progresses gradually and the particular degradation phenomenon is observed.

The natural degradation of Iupilon / NOVAREX begins by the photo-oxidation reaction based on ultraviolet ray near the wavelength of 290nm. The most remarkable phenomenon is the change of the surface layer resulted in various changes of chemical structure such as the formation of cross linkage and gel, decrease in molecular weight by discoloring to yellow and break in the main chain, the mechanical strength and flexibility are reduced and finally cracks occur.

The change in ultraviolet transmittance of Iupilon / NOVAREX that irradiated by ultraviolet ray and outdoor exposure is shown in Fig. 7・2－1 and 7・2－2. The change when irradiated in solution and the change in discoloring to yellow by outdoor exposure are shown in Fig. 7・2－3 and 7・2－4, respectively.
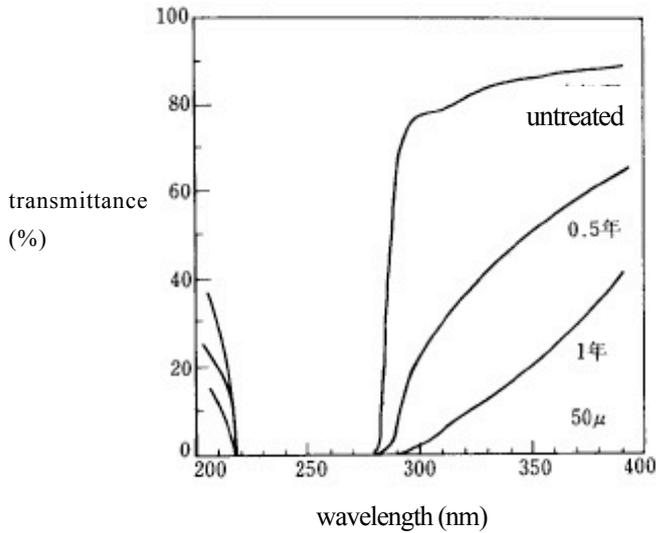
Fig. 7・2－1 Change in ultraviolet transmittance by outdoor exposure
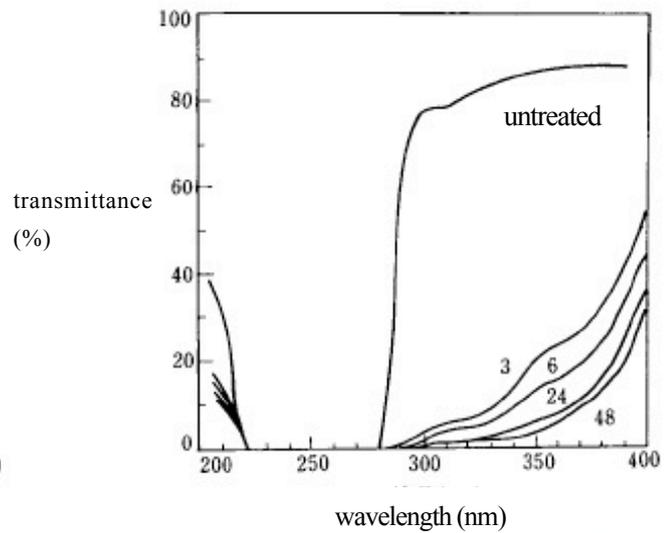
Fig. 7・2－2 Change in ultraviolet transmittance by ultraviolet radiation (time)
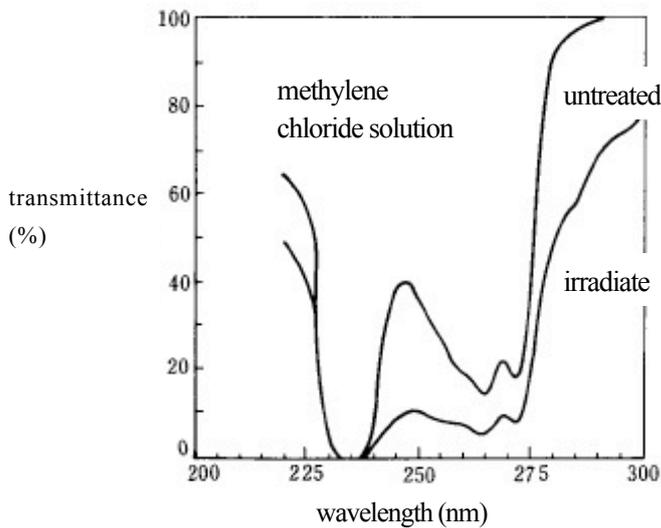
Fig. 7・2－3 Change in ultraviolet transmittance by ultraviolet radiation
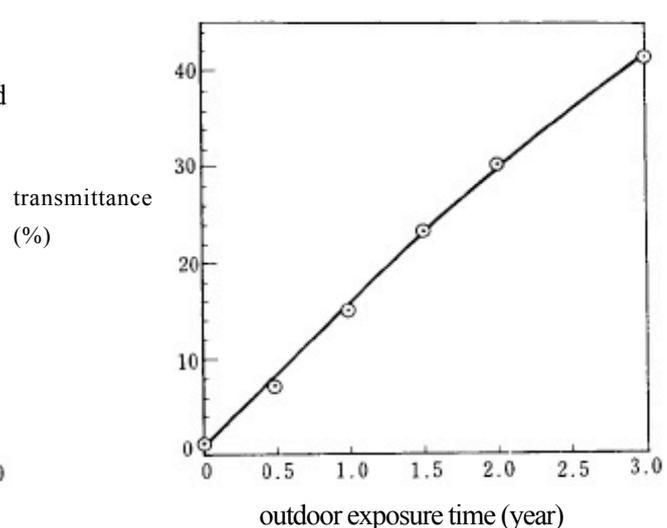
Fig. 7・2－4 Change in discoloring to yellow by outdoor exposure

The change in infrared absorption spectrum by exposure to ultraviolet ray was shown in Fig. 7・2－5 and 7・2－6, respectively. As shown in Fig. 7・2－5, the increase in －OH group, decrease of －CH3 group, ＞C＝0 group are observed, and the absorption of the ester and benzophenone groups appears at 1720cm -1, 1630cm -1.

Fig. 7・2－6 shows the multi reflection infrared-absorption spectrum which indicated the chemical structure change at the surface layer after the irradiation. The change in the absorption strength at 1775cm-1 is shown clearly, and it is a very considerable change. The change of this carbonic acid group was shown in Fig. 7・2－7.

The surface layer that caused the degradation is insoluble in methylene chloride, and it can be considered that obviously, the branch and cross-linking reaction take place. The formation of this gel layer is as shown in Fig. 7・2－8.
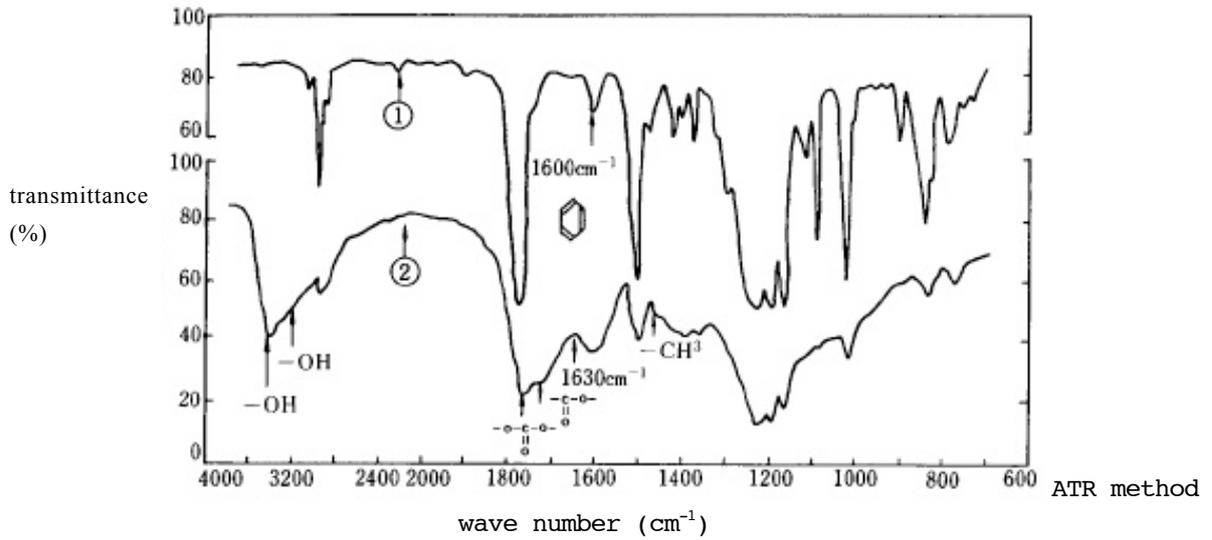
① Unirradiated（Iupilon / NOVAREX） ② Irradiated（Iupilon / NOVAREX） Insoluble matter in methylene chloride

Fig. 7・2－5 Change in infrared absorption spectrum by exposure to ultraviolet ray
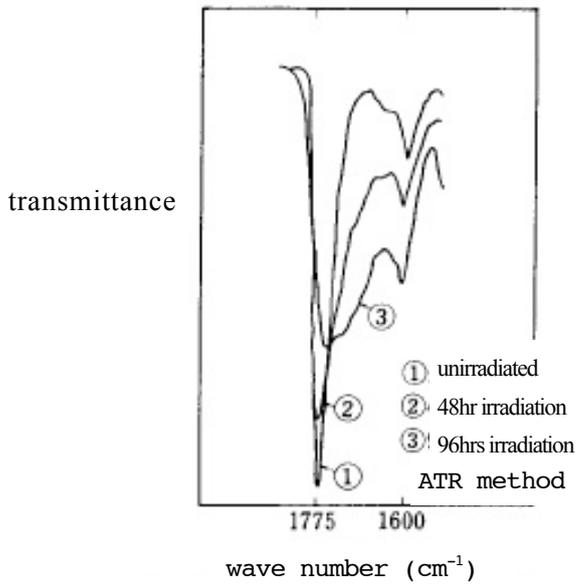

1775cm -1 : Carbonic acid bond（＞C＝0）
1600cm -1 : Double bond of benzene ringg

Fig. 7・2－6　Change in infrared absorption spectrum by exposure to ultraviolet ray (change in carbonic acid bond)
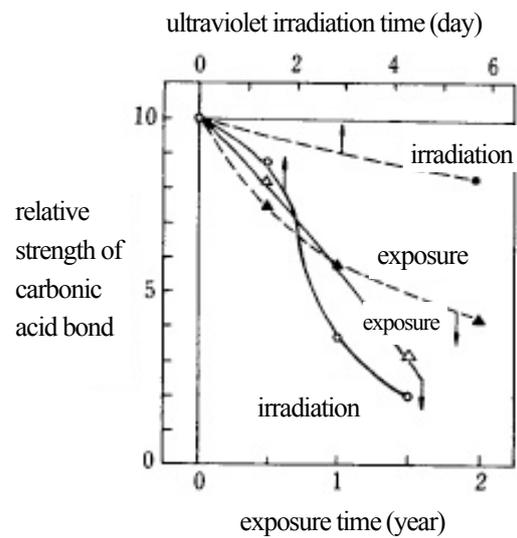
···▲···●···sample back side

Fig. 7・2－7　Change in carbonic acid bond
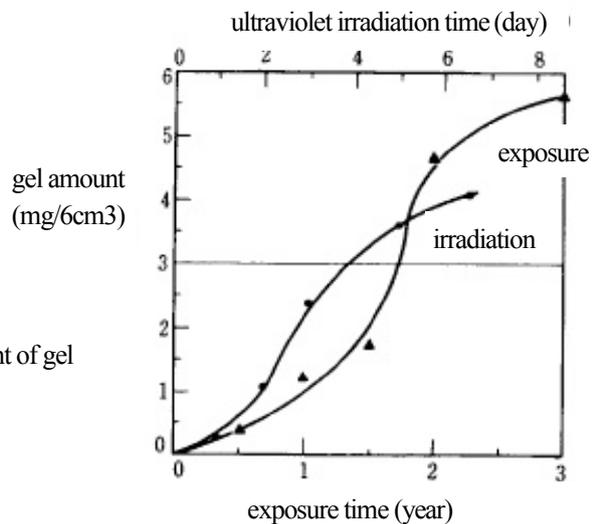
Fig. 7・2－8　Formation amount of gel

The results of outdoor exposure test and weather meter of Iupilon / NOVAREX are shown in Fig. 7・2－9, 10, 11, 12 and 13.
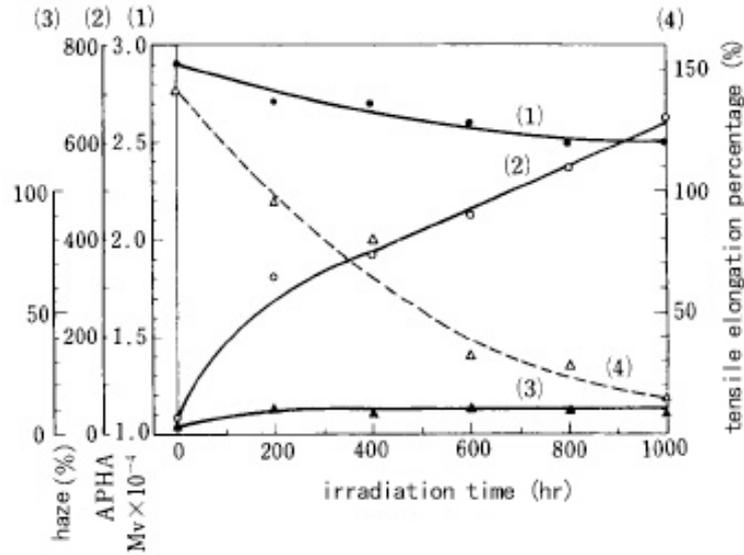

Fig. 7・2－9 Degradation by sunshine type weather meter (thickness 200μm)
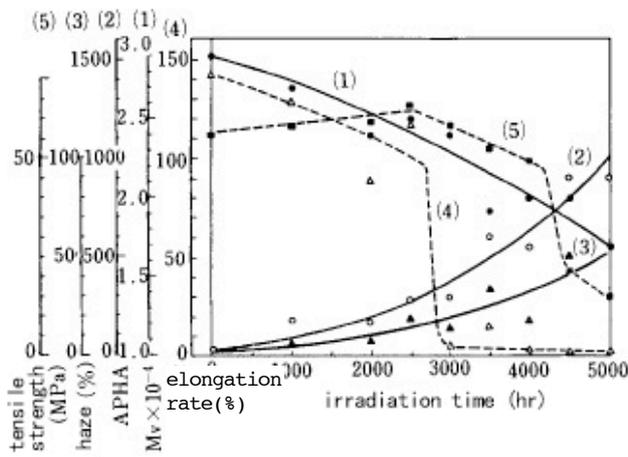
Fig. 7・2－10 Degradation by weather meter (thickness 200μm)
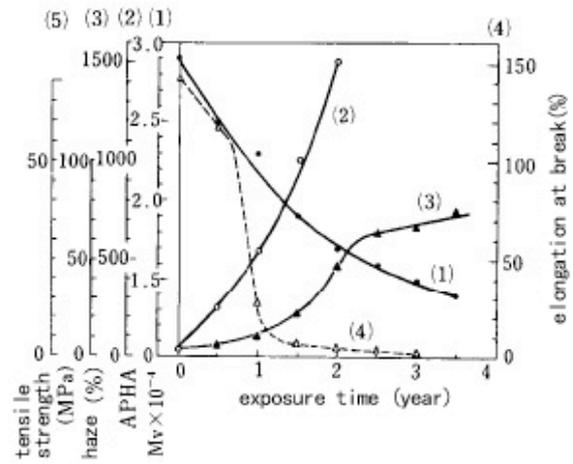
Fig. 7・2－11 Degradation by outdoor exposure test (thickness 200μm)
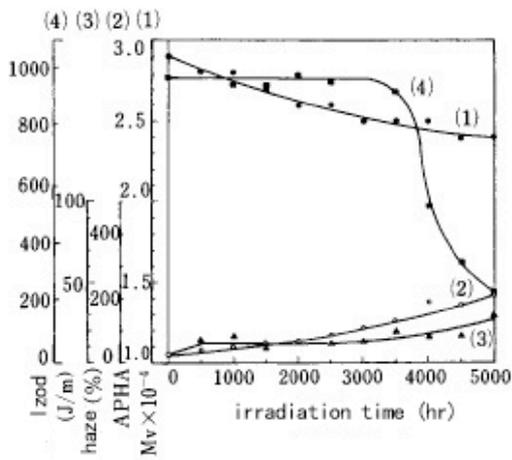

Fig. 7・2－12 Degradation by weather meter (thickness 3.2mm)
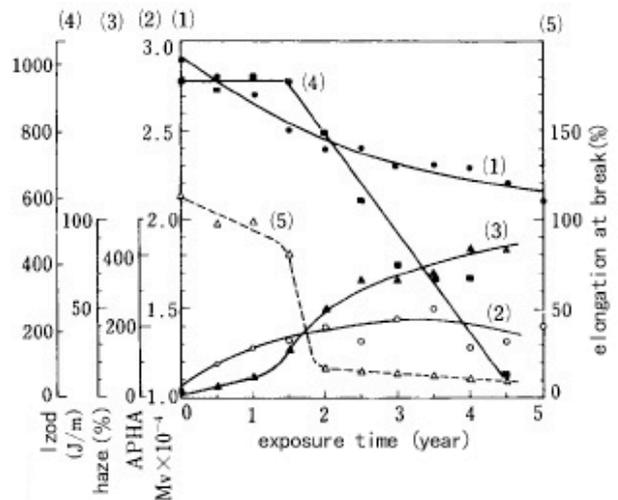
Fig.7・2－13   Degradation by outdoor exposure (thickness 3.2mm)

The above results have the distinctive changes as follows:

(1) A remarkable difference in discoloring to yellow by the sample thickness is observed
    but the difference in haze is hardly detected.

(2) Though the molecular weight is high enough, the brittleness is shown by tensile test.

Such a change is big near the surface layer, but conversely it means that the inside is protected by the surface layer.

Therefore, it can be considered that the relationship between the degradation and sample thickness is significant.

Fig. 7・2－14 (change of carbonic acid group 1770cm^{-1} of infrared spectrum), Fig. 7・2－15 (APHA),

Fig. 7・2－16 (〔η〕), Fig. 7・2－17 (Mv) and Fig. 7・2－18 (Mv) are the results which show the influence by thickness.

As for the method of improving the weather resistance of Iupilon / NOVAREX, the addition of ultraviolet absorber

and stabilizer or inorganic filling agent can be considered as the most usual method.
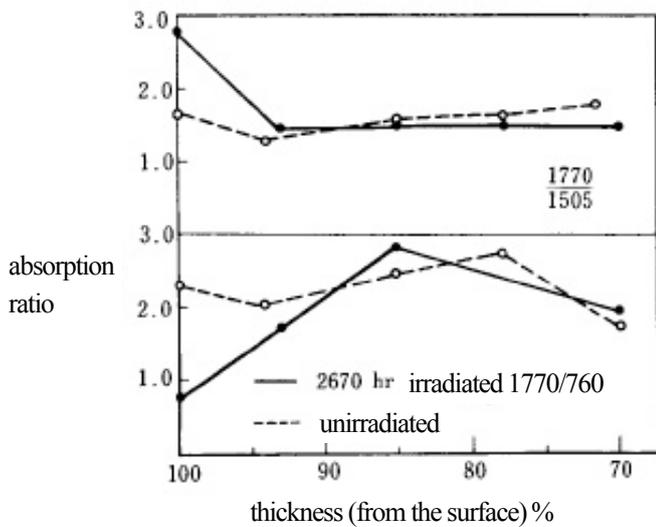
Fig. 7・2－14 Change status of carbonic acid group by thickness
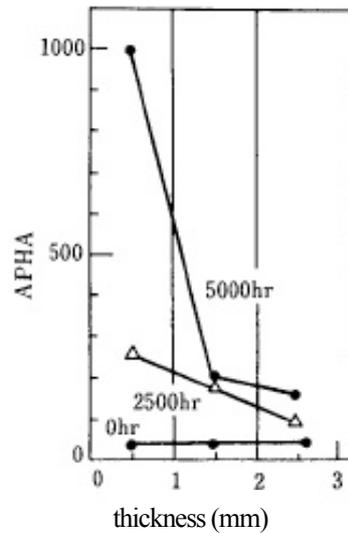
Fig. 7・2－15 Difference in APHA by weather meter
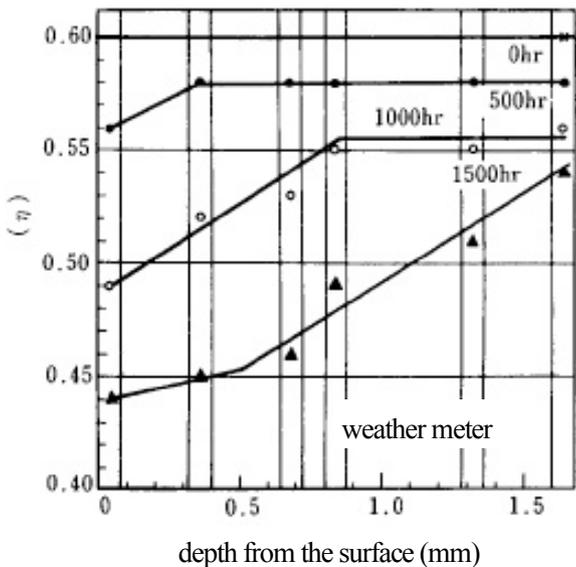
Fig.7・2－16　Difference in molecular weight decrease by thickness
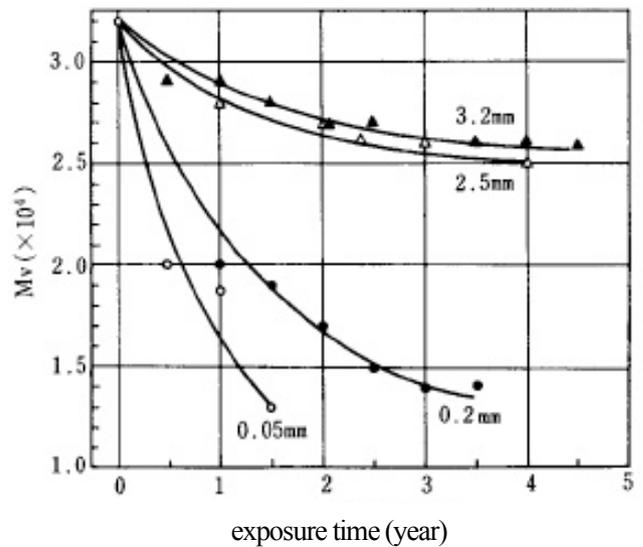
Fig. 7・2－17　Relation between molecular weight decrease and sample thickness at exposure degradation
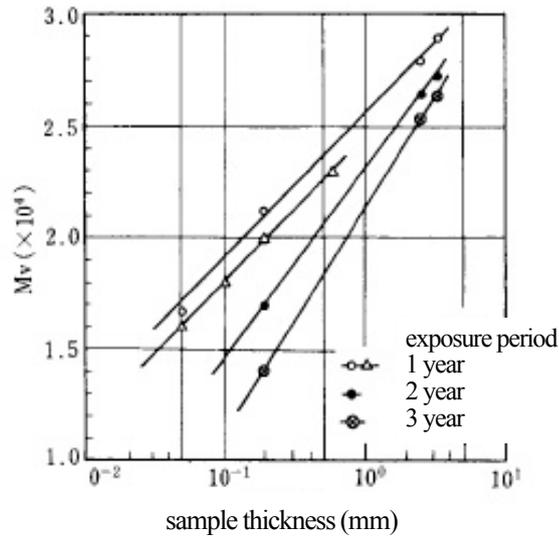
Fig. 7・2−18   Relation between molecular weight (Mv) decrease and sample thickness

Fig. 7・2−19 (yellowing degree), Fig. 7・2−20 (Mv), Fig. 7・2−21 (tensile break elongation rate), Fig. 7・2−22 (tensile strength), Fig. 7・2−23 (flexural strength), Fig. 7・2−24 (transparency and haze) and Fig. 7・2−25 (APHA) show the effects of UV absorber addition.
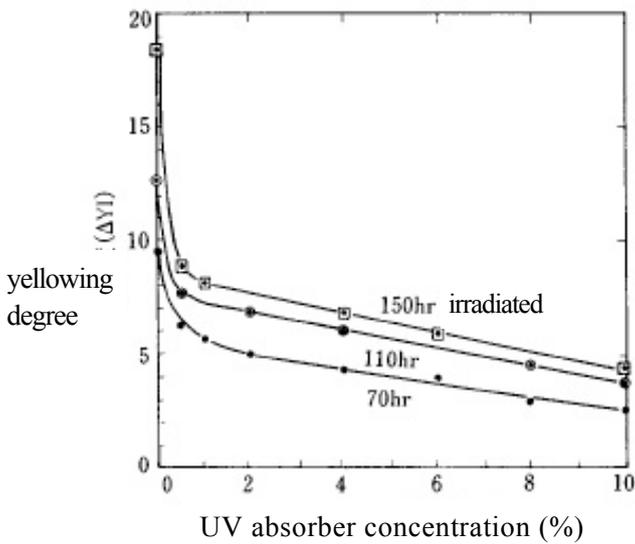
Fig. 7・2−19 Relation between UV absorber concentration and yellowing degree by UV irradiation
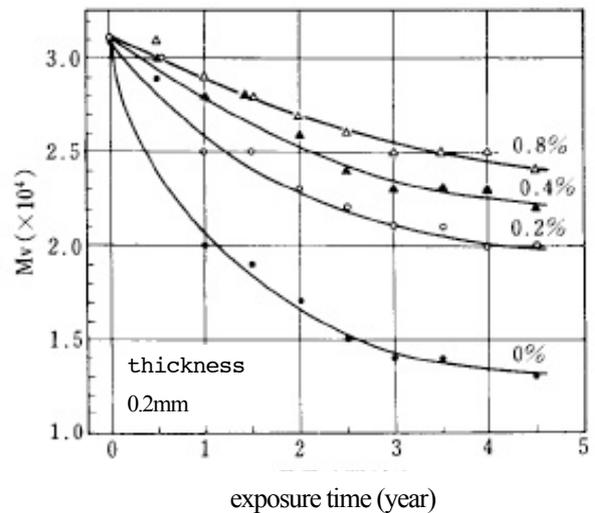
Fig. 7・2−20 UV absorbent content and molecular weight decrease by exposure test
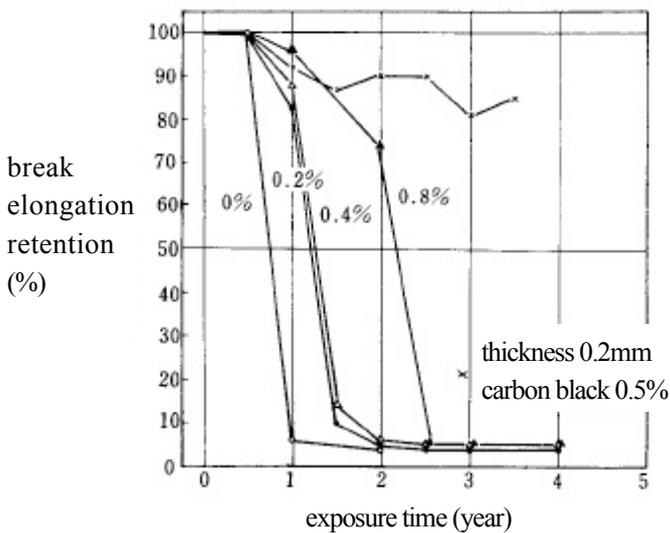
Fig. 7・2−21 Relation between UV absorber content and tensile break elongation rate decrease by exposure test
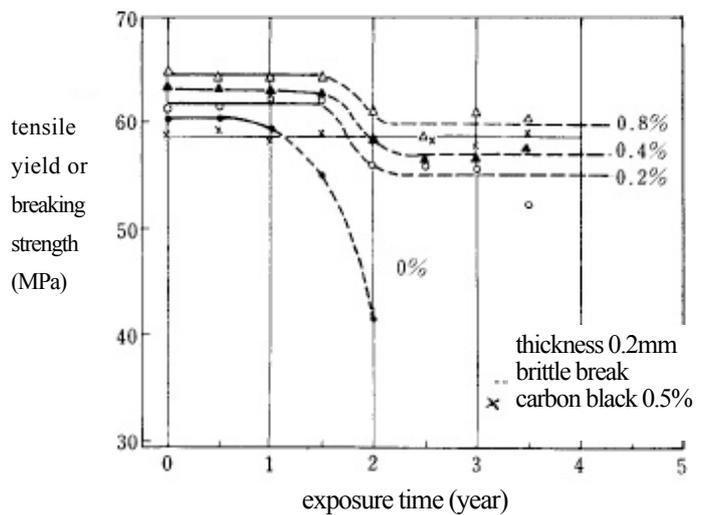
Fig. 7・2−22 Relation between UV absorber and tensile strength change by exposure test
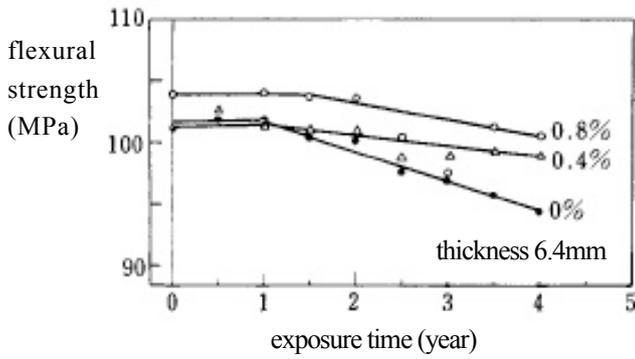
Fig. 7・2－23　Change in flexural strength by exposure test
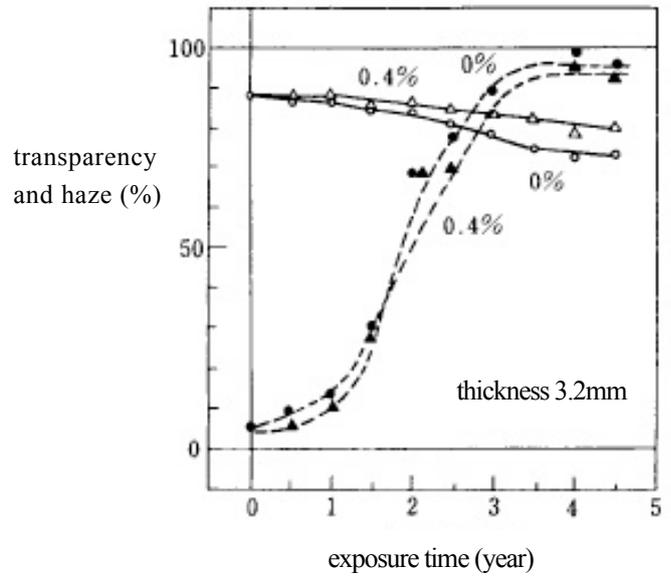
Fig. 7・2－24　Change in transparency and haze by exposure
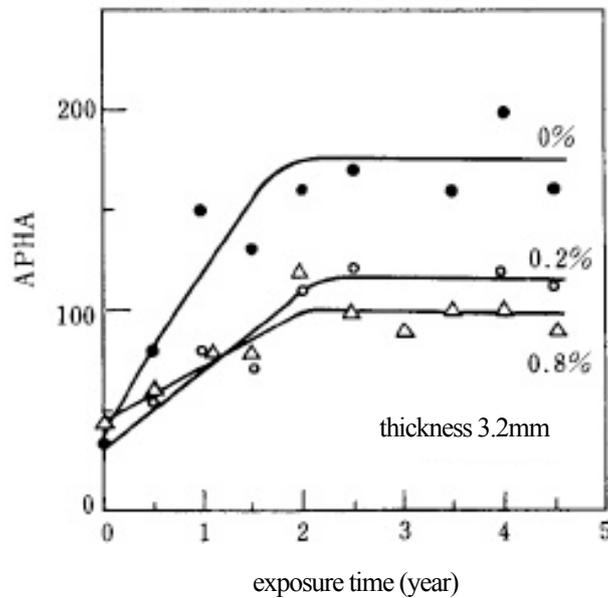
Fig. 7・2－25　Yellowed property by exposure

The addition of ultraviolet absorber shows the effect to each physical property, but it does not necessarily say that it is enough. As mentioned before, because polycarbonate is considerably influenced by the thickness, it is necessary to consider the stabilized sample.

Fig. 7・2－26 (Mv), Fig. 7・2－27 (tensile property), Fig. 7・2－28 (break elongation) and Fig. 7・2－29 (APHA) showed the influence of thickness on the weathering resistance of the sample containing 0.4% of UV absorber. If the thickness is 0.45mm, the molecular weight decrease is small, and it turns out that the breaking situation can also maintain the ductile breaking state.
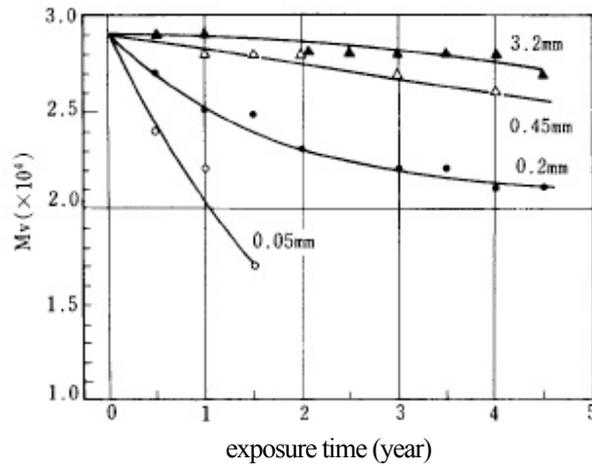
Sample $Mv = 2.9 \times 10^4$ containing 0.4% of UV absorber

Fig. 7・2－26 Influence of sample thickness on molecular weight (Mv) decrease
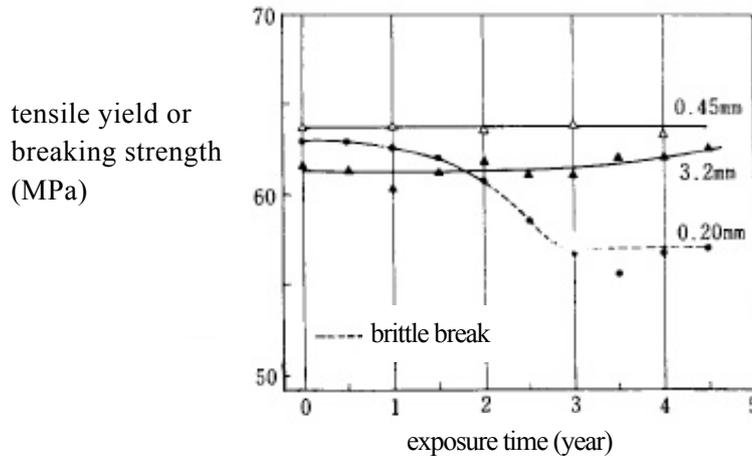
Fig. 7・2－27 Relation between sample thickness and change in tensile strength
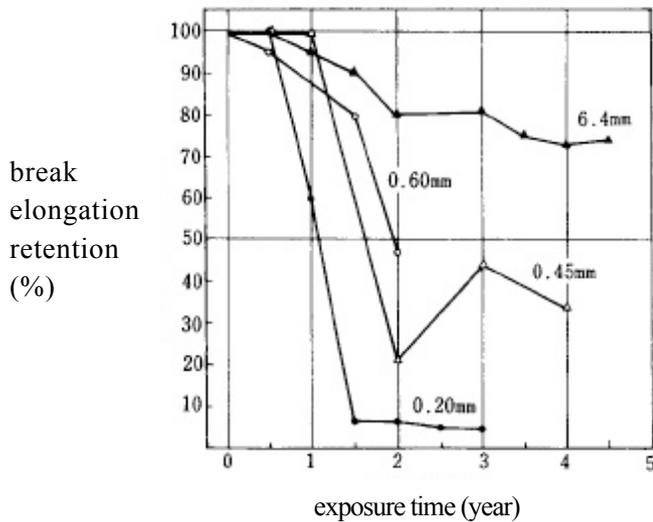
Sample: containing 0.4% of UV absorber

Fig. 7・2－28 Relation between sample thickness and break elongation decrease
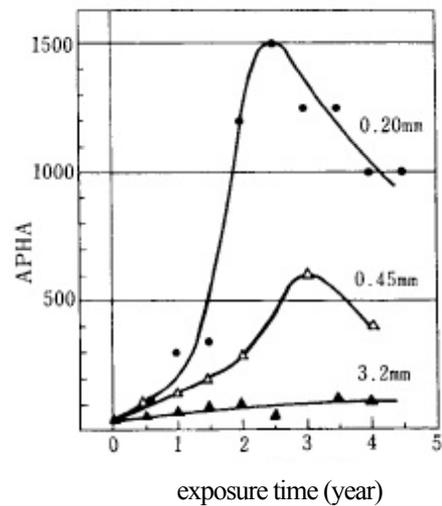
Fig. 7・2－29 Relation between sample thickness and APHA change

Next, the effect of the addition of inorganic filling agent in the improvement of the weathering resistance is also known. The typical example is carbon black, as shown in Fig. 7・2－21 and 7・2－22, the fact that it is more effective than the ultraviolet absorber in Iupilon / NOVAREX is indicated.

From this meaning, the result of examining the inorganic pigment was shown in Table 7・2－1. In addition, the result of the long-term exposure test of the sample containing titanium white was shown in Table 7・2－2.

Table 7・2－1 Influence of pigment addition in outdoor exposure test

Type of pigment		Additive amount （%）	pH	Untreated Molecular weight （×10⁴)	Outdoor exposure 1 year		Thickness （μm）
					Molecular weight （×10⁴)	ΔE	
Blue pigment		0. 2	9. 4	2. 8	2. 1	5. 6	50
Red oxide		0. 2	7. 6	2. 8	2. 1	4. 9	50
Shanin green		0. 2	6. 5	2. 8	2. 1	4. 3	50
Cadmium yellow	M3600	0. 2	7. 3	2. 8	2. 1	2. 2	50
Cadmium yellow	M3200	0. 2	7. 2	2. 8	2. 1	1. 8	50
Cadmium red	L6600	0. 2	8. 2	2. 8	2. 2	2. 6	50
Cadmium red	M8300	0. 2	8. 2	2. 8	2. 1	2. 7	50
Cadmium red	05700	0. 2	8. 1	2. 8	2. 6	2. 9	50
Shanin blue	LBGT	0. 2	8. 0	2. 8	2. 3	1. 0	50
Carbon black							
Nippiru#100 （Nittetsu）		0. 5	4. 7	2. 8	2. 4	3. 0	50
FB44 （ Mitsubishi carbon）		0. 5	7. 7	2. 8	2. 3	3. 8	50
#50 （ Mitsubishi carbon）		0. 5	6. 0	2. 8	2. 3	4. 5	50
#600 （ Mitsubishi carbon）		0. 5	7. 0	2. 8	2. 5	5. 6	50
For rubber H （ 〝 ）		0. 5	7. 7	2. 8	2. 5	2. 5	50
Mark （Columbia）		0. 5	3. 0	2. 8	2. 4	9. 0	50
#999 （Columbia）		0. 5	3. 9	2. 8	2. 3	7. 0	50
Blank		0		2. 8	1. 8	8. 2	50
Titanium white R820		0. 7		2. 8		13. 6	200
Titanium white R101		0. 7		2. 8		14. 4	200
Carbon black （for rubber H）		0. 5		2. 8		2. 0	200
Carbon black （#100）		0. 5		2. 8	2. 6	4. 4	200
Blank		0		2. 8	2. 0	11. 0	200

Table 7・2－2　Influence of UV, TiO₂ in exposure test

	Additives （%）		Change in Mv by exposure test （×10⁴)					Generation rate of brittle break by falling ball test （%）				
	UV	TiO₂	0 year	2years	3years	4years	5years	0 year	1 year	2 years	3 years	4 years
1	0	0	3. 1	2. 8	2. 7	2. 6	2. 5	0	90	100	100	100
2	0. 4	0	3. 1	3. 0	3. 0	3. 0	3. 0	0	0	0	0	0
3	0	0. 5	3. 1	2. 8	2. 6	2. 6	2. 6	0	5	15	100	100
4	0. 4	0. 5	3. 0	2. 7	2. 6	2. 6	2. 6	0	0	0	0	25

Sample thickness 2.5mm, UV: ultraviolet absorber
The falling ball test drops the steel ball of 3.6kg from the height of 3.85m on a hemisphere body of 146mm inside diameter and examines the breaking situation.

7・3　Degradation by Irradiation

When polycarbonate is irradiated with the electron beam, the radiation, and the X-ray etc. the degradation takes place. For example, the analysis result of gas generated when polycarbonate is irradiated with the gamma ray was shown in Table 7・3－1. From this, a large part of CO_2, CO gas generation, and some amount of CH_4, H_2 are observed. From the above results, it can be said that the degradation of polycarbonate results from the break in the main chain as the most part, and some sub-degradation as shown in the following formula.

Table 7・3－1　Gas generated by gamma-irradiation (gas generated rate %)

Irradiance level (γ)	Weight decrease (%)	CO	CO_2	H_2	CH_2	$CO／CO_2$
1×10^8	0. 33	79. 3	15. 8	4. 5	0. 4	0. 4
2×10^8	0. 70					1. 8
3×10^8	1. 54	61. 6	34. 4	3. 2	0. 8	
10×10^8		61. 2	31. 0	7. 0	0. 8	2. 0

If the degradation of polycarbonate by irradiation takes place by the break in the main chain, as a matter of fact, the average molecular weight decrease (Fig. 7・3－1) and the degradation of mechanical properties (Fig. 7・3－2) are observed.
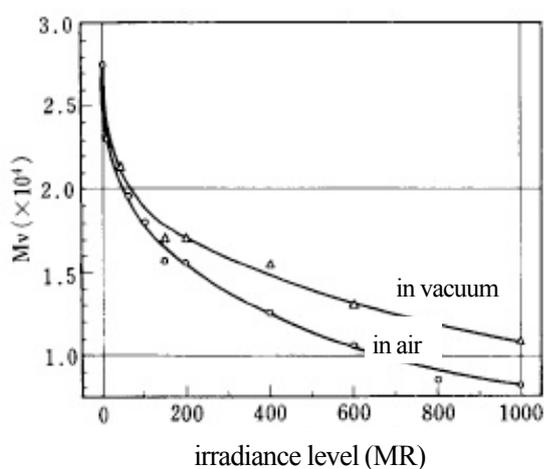
Fig. 7・3－1 Decrease in molecular weight by irradiation
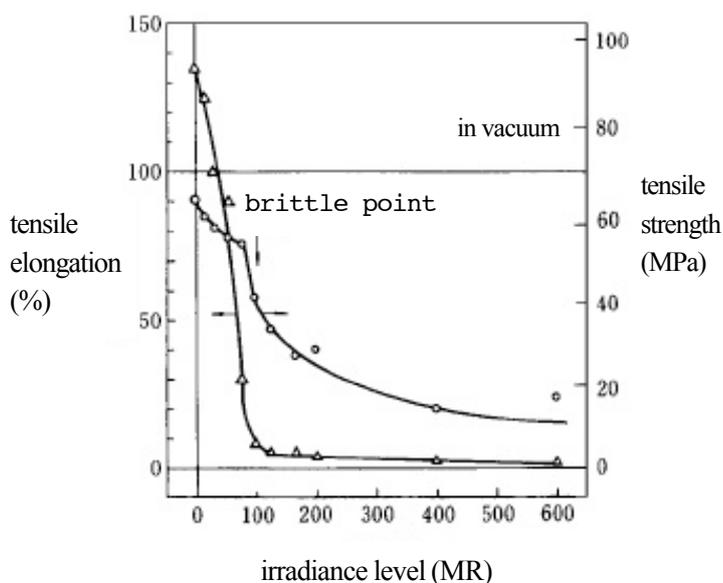
Fig. 7・3－2 Change in tensile property by irradiation

The degradation by irradiation and a comparison with other resins are shown in Table 7・3－2 and Table 7・3－3, respectively.

Table 7・3－2　Gas generated by decomposition of various resins by gamma-irradiation（μ mol／g）

Polymers	CO_2	H_2	CO	Methane	Ethane	Butane	Butene	Methyl chloride	Pentene	Methanol
Polycarbonate	32. 5	1. 5	66. 0				4. 6	4. 0	1. 6	
Polyester 1	56. 3	33. 5								
Polyester 2	82. 0	18. 0								
High density polyethylene	3. 0	92. 0	5. 0							
Low density polyethylene	1. 0	91. 0	1. 0		2. 0	3. 5	1. 5			
Polypropylene	1. 0	95. 0	1. 0	3. 0						
66 Nylon	5. 0	71. 0	24. 0							
11 Nylon	1. 0	66. 0	29. 0	4. 0						
Chlorinated polyether	8. 7	85. 8					1. 4	3. 8	0. 3	
Polyacetal	69. 0	7. 5		15. 0						2. 0

6 M r a d　i n　v a c u u m

Table 7・3－3 Comparison of generation amount of decomposed gas by gamma-irradiation

Order	Generation amount of gas （1）	
1	Below 1	Polyester 1, Polyester 2, Polyethylene, Polychlorotrifluoroethylene
2	1－5	Polycarbonate, 66 Nylon, Polyamide11, Chlorinated polyether
3	5－10	Polyvinylidene chloride
4	10－15	Polyvinyl chloride, Polyethylene of polyester coating
5	15－20	Polyethylene, Polypropylene
6	Above 50	Polyacetal

International System of Units （SI units）

Main Unit Conversion Table

Force	N	dyn	kgf		
	1	1×10^5	1.01972×10^{-1}		
	1×10^{-5}	1	1.01972×10^{-6}		
	9.80665	9.80665×10^5	1		

Pressure	Pa	kgf/cm^2	atm	mmHg・Torr	
	1	1.01972×10^{-5}	9.86923×10^{-6}	7.50062×10^{-3}	
	9.80665×10^4	1	9.67841×10^{-1}	7.35559×10^2	
	1.01325×10^5	1.03323	1	7.60000×10^2	
	1.33322×10^2	1.35951×10^{-3}	1.31579×10^{-3}	1	

Stress	Pa or N/m^2	kgf/mm^2	kgf/cm^2		
	1	1.01972×10^{-7}	1.01972×10^{-5}		
	9.80665×10^6	1	1×10^2		
	9.80665×10^4	1×10^{-2}	1		

Energy・Work・Heat	J	kW・h	kgf・m	kcal	
	1	2.77778×10^{-7}	1.01972×10^{-1}	2.38889×10^{-4}	
	3.600×10^6	1	3.67098×10^5	8.6000×10^2	
	9.80665	2.72407×10^{-6}	1	2.34270×10^{-3}	
	4.18605×10^3	1.16279×10^{-3}	4.26858×10^2	1	

Power	W	kgf・m/S	PS	kcal/h	
	1	1.01972×10^{-1}	1.35962×10^{-3}	8.5985×10^{-1}	
	9.80665	1	1.33333×10^{-2}	8.43371	
	7.355×10^2	7.5×10	1	6.32529×10^2	
	1.16279	1.18572×10^{-1}	1.58095×10^{-3}	1	

Viscosity (viscous modulus)	Pa・S	cP	P		
	1	1×10^3	1×10		
	1×10^{-3}	1	1×10^{-2}		
	1×10^{-1}	1×10^2	1		

Kinetic viscosity (kinematic viscosity coefficient）	m^2/S	cSt	St		
	1	1×10^6	1×10^4		
	1×10^{-6}	1	1×10^{-2}		
	1×10^{-4}	1×10^2	1		

Heat conductivity	W／ (m・K)	kcal／ (h・m・℃)			
	1	8.6000×10^{-1}			
	1.16279	1			

Specific heat	J／ (kg・K)	kcal／ (kg・℃) cal／ (g・℃)			
	1	2.38889×10^{-4}			
	4.18605×10^{3}	1			

CAUTION

● Data described in this catalog are typical examples of the measurement by our company's test method.

● The use application described in this catalog does not guarantee the application result to the said usage of this product.

● Please consider the industrial property and use conditions etc. related to the usage and application described in this catalog in your company.

● Please refer to the used material, technical information of the grade and product safety data sheet (MSDS) in the handling of this product (transportation, storage, molding, disposal etc.).

Especially, please confirm safety sufficiently when using the food container wrapping, medical parts, safety tool, and toys for infants etc.

● The chemicals (carbon black, titanium oxide, zinc oxide) that should notify in applicable laws and regulations, Item 2 of the Article 57 of the Occupational Health and Safety Law, Item 2 of the enforcement order 18, name in attached table 9 etc. may be contained in case of each grade colored article of this product. Please contact for the details.

● Because some items of the MEP products correspond to specified articles of the controlled target products under the Export Trade Control Ordinance, please contact for the details.

Please conform to the applicable laws and regulations of the Foreign Exchange and Foreign Trade Control Law etc. when conducting the export and sale of the MEP product and the product that included it.

● The deterioration of some articles in this product may occur due to the residual fumigant which is used for the fumigation treatment of the wooden pallet.

Please refrain from carrying out the fumigation treatment by loading the corresponding product on the wooden pallet or loading on the wooden pallet that the fumigation was treated.

● There is a possibility that harmful gas and fume are generated by the heat decomposition of the resin at the time of molding and cleaning the tack.

Please install the ventilator for the local or the whole ventilation.

● When the product which added fluorocarbon resin is heated above 250℃, the poisonous gas may be generated due to the decomposition of fluorocarbon resin. Therefore, the ventilation of work environment should be done sufficiently. Also, please do not burn this product when disposing it but carry out the landfill instead.

※Please acknowledge that the contents of this catalog might be changed without notice for the revision.